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Summary

We have developed a cost-effective method for accelerating the thermal wavefront recovery and shot rate of large, flashlamp-pumped, Nd:glass, Brewster-angle slab lasers of the type used for studying inertial confinement fusion (ICF) and laser-plasma interactions. This method removes waste pump heat by flowing slightly-chilled, turbulent gas over the flashlamps and blastshields after each shot, with the cooled blastshields serving as heat sinks for radiatively extracting residual heat deposited in the laser slabs. We performed both experiments and modeling to characterize residual optical distortions arising from both temperature gradients within the laser slabs as well as from buoyantly-driven convection currents in the amplifier cavity and attached beam tubes. The most rapid thermal recovery was achieved by reducing the temperature of the cooling gas by $0.5 - 1^{\circ}\text{C}$ below the ambient temperature for about two hours after the shot. Model predictions for the 1.8-MJ National Ignition Facility (NIF) laser now being built at Lawrence Livermore National Laboratory (LLNL) show that such chilled-gas cooling would increase the thermal-distortion-limited shot rate from about one shot every eight hours to one shot every three to four hours, thus significantly increasing the potential scientific productivity of this major Department of Energy (DOE) facility.

Introduction

Flashlamp-pumped neodymium glass lasers used for ICF experiments must produce high-quality laser beams to heat targets to high temperatures and densities. They must also maintain high repetition rates to be productive and cost effective. The two requirements are often difficult to meet simultaneously, however, due to waste heat deposited in the amplifying neodymium-doped laser slabs by flashlamp pumping processes. The thermal gradients generated by waste heat, which occur not only in the laser slabs but also in the gas that is convectively heated by the slabs, cause refractive-index variations and beam wavefront distortion that persist for many hours after each shot. In modern ICF laser systems, in which the beam is passed through the amplifiers several times for efficient usage of hardware, temperature variations as small as 0.1°C in the laser slabs can produce

several waves of beam distortion. Thus, management of thermal distortion will be a critical factor determining the performance and scientific productivity of large ICF laser facilities such as the National Ignition Facility (NIF) in the US and the Laser Megajoule (LMJ) in France.

Amplifiers used in previous flashlamp-pumped ICF laser systems have been cooled passively or by flowing water over the flashlamps. Although passively-cooled lasers generally have excellent wavefront quality and laser-beam focusability for the first shot taken each day, performance degrades monotonically as shots are accumulated and heat builds up in the amplifiers. Examples of passively-cooled ICF lasers include the Shiva, Nova, and Beamlet lasers built at LLNL; the Phebus laser built at the Centre d'Etudes de Limeil-Valenton in France; and the Gekko laser at Osaka in Japan.

In contrast, the Omega laser at the University of Rochester achieves relatively rapid thermal recovery, in approximately 20 minutes after each shot, by flowing water over the flashlamps. Using water for cooling has the disadvantage of adding cost and complexity, however, as water-jacket tubes need to be placed around each flashlamp to define the flow channel. Due to the space taken up by the water jacket tubes, additional consequences of water cooling are a reduction in the number of flashlamps that can be inserted in the pump cavity and added constraints on the shapes of flashlamp reflectors, with attendant undesirable effects on gain and gain uniformity. While these undesirable effects have little or no impact on the Omega amplifiers, which use one beam per amplifier box, they have significant impact on the highly-efficient multisegment amplifiers planned for the National Ignition Facility, which use eight beams per box to reduce space requirements and cost. In such amplifiers, the impact is greatest on the central flashlamp arrays, which pump laser slabs in both directions. Flashlamps in the central arrays must be packed close together to meet gain requirements, and reflectors must be placed near the flashlamps to adequately control pump-light distributions incident on the laser slabs.

Purpose

The purpose of this LDRD work was to develop for large, multisegment, flashlamp-pumped Nd:glass amplifiers a cost-effective method for accelerating thermal recovery and shot-rate without compromising gain or gain uniformity.

Approach

The method we chose for accelerating amplifier thermal recovery was to flow slightly-chilled, turbulent gas over the flashlamps. In our implementation, gas cooling channels are defined by the flashlamps, metal reflectors, and blastshields. Blastshields are optically transmissive glass plates installed between the flashlamps and laser slabs, used to protect the laser slabs from contamination and to prevent acoustic waves generated by the mechanical motion of the flashlamp envelopes from propagating into the beam path and causing wavefront distortion. Preliminary modeling suggested that gas cooling would be an effective way to accelerate shot rate, as the flashlamps, which retain most of the thermal energy produced in the amplifiers, would be cooled before their thermal energy was transferred to the blastshields and laser slabs. In addition, thermal energy deposited in the laser slabs would eventually be carried away by the gas, after transferring radiatively to the blastshields.

Activities and Results

We performed both experiments and modeling to characterize the recovery of thermal wavefronts. Our experiments included a demonstration of a full-scale NIF prototype amplifier in which thermal recovery was accelerated by flowing turbulent air over the flashlamps. Temperatures of selected laser slabs, blastshields, flashlamps, and reflectors were measured with thermocouples, while wavefront distortions were measured with a Twyman-Green interferometer. The amplifier was tested in two- and three-slab-long configurations. Measurements were compared with predictions made with a three-

dimensional (3D), finite-element thermal model that simulated thermal radiation, conduction, and forced-air cooling.

Our analysis shows that the NIF amplifiers should meet their thermal-recovery criteria within 3 to 5 h after each shot, provided the flashlamps are cooled with slightly chilled, turbulent gas. Average slab temperatures were in close agreement with predictions made with the 3D model. Measured gas distortions varied nearly linearly with the difference between the average slab temperature and the ambient temperature.

To estimate the effect of wavefront distortions on the NIF laser beams, we scaled the measured gas distortions to account for the greater path length through the NIF amplifiers and used a beam-propagation code to calculate the beams' focal spot. Our estimate shows that the gas distortions will meet the NIF requirement (less than 5 mrad added beam divergence) with 2 to 3 h after the shot, provided the temperature of the flashlamp-cooling gas is about 1 C below the ambient temperature. Further, the measured distortions of the slabs were of sufficiently low order and magnitude to be correctable – within 3-4 h after each shot – by the deformable-mirror system now anticipated for the NIF.

Detailed Documentation

For detailed descriptions of the experiments and modeling performed to develop the amplifier cooling method, the reader is referred to the following publications:

1. S. Sutton, A. Erlandson, R. London, K. Manes, C. Marshall, C. Petty, R. Pierce, L. Smith, and L. Zapata, "Thermal Recovery of the NIF Amplifiers," Proceedings of SPIE: Third International Conference on Solid State Lasers for Application to Inertial Confinement Fusion, 7-9 June 1998, Monterey, California, Vol. 3492, pp. 665 – 670 (1999).
2. A C. Erlandson et al., "Physics Basis for Optical Performance of the NIF Amplifiers," UCRL-ID-132680, NIF-0014142, January 11, 1999.
3. A. C. Erlandson et al., "Design and Performance of Flashlamp-Pumped Nd:glass Amplifiers for the NIF," ICF Quarterly Report 8(4), pp. 162 – 170, Lawrence Livermore National Laboratory, CA, UCRL-LR-105821-98-4 (1999).